NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

NAVAL COMMUNICATIONS PROCESSING
AND ROUTING SYSTEM (NAVCOMPARS):
A MODEL FOR BROADCAST PERFORMANCE ANALYSIS

by

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March 1983

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Naval Communications Processing and Routing System (NAVCOMPARS): A Model for Broadcast Performance Analysis		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; March 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Gary L. George		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE March 1983
		13. NUMBER OF PAGES 52
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

NAVCOMPARS; Queuing Theory; Multichannel Broadcast

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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Naval Communications Processing and Routing System (NAVCOMPARS): A Model for Broadcast Performance Analysis

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN TELECOMMUNICATIONS SYSTEMS MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
March 1983

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This thesis represents an analysis of the performance of the Naval Telecommunications System's (NTS) multichannel broadcast. It highlights the speed differential between the Naval Communications Processing And Routing System's (NAVCOMPARS) processing subsystems and the multichannel broadcast's transmission lines.

In this effort, the message flow through the NAVCOMPARS is described. An analytic approach was chosen and input statistics, such as average message length and input rates, were gathered for queuing analysis. The operational characteristic upon which broadcast performance is evaluated is the average time delay in the system. The broadcast channel's ability to satisfy future communications requirements is also examined. The analysis demonstrates that, unless the increasing trends in message input rates are reversed or message lengths reduced, a dedicated broadcast overload channel would be required to meet communications requirements throughout the 1980's.

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TABLE OF ABBREVIATIONS

AUTODIN	Automatic Digital Network
baud	Number of times per second that a transmitted signal changes its value
BCSN	Broadcast Control Sequence Number
bps	bits per second
BSR	Broadcast Service Request
byte	eight bits
CCS	Communications Control Subsystem
CDA	Common Data Area
CDF	Cummulative Distribution Function
CMS	Configuration Management Subsystem
CPU	Central Processing Unit
CUDIXS	Common User Digital Information Exchange Subsystem
DCA	Defense Communications Agency
EBCDIC	Extended Binary Coded Decimal Interchange Code
FEP	Front End Processor
FIFO	First-In First-Out
HF	High Frequency
HMCC	Broadcast Common Channel
I/O	Input/Output
JCS	Joint Chiefs of Staff

MPDSK	Message Processing Subsystem's Magnetic Disk
MPS	Message Processing Subsystem
NAVCOMPARS	Naval Communications Processing and Routing System
NTS	Naval Telecommunications System
OCR	Optical Character Reader
PSN	Processing Sequence Number
RADAY	Radio Day
RCDSK	Receivce Control Subsystem's Magnetic Disk
RCS	Receive Control Subsystem
SPS	Support Program Subsystem
SRPA	SPS Traffic Analysis Report
SVC	Supervisor Calls
TCS	Transmission Control Subsystem
TDM	Time Division Multiplex
TI	Transmission Indicator
TPS	Transmission Processing Subsystem
TTY	Teletype
VDT	Video Display Terminal
Xmission	Transmission

TABLE OF SYMBOLS

$\bar{X}$	Arithmetic mean
σ_X	Standard Deviation
ϵ	base of the natural logarithm
C	Channel's transmission speed (baud rate)
λ	Average message input rate
l	Average message length
μ	Average transmission Rate
ρ	Channel utilization
P	Number of Precedence levels
N	Number of Observations
W_P	Waiting Time within the Transmission Queue
t	Transmission Time
T	Total time in the System

I. INTRODUCTION

A. BACKGROUND

The mission of the Naval Telecommunications System (NTS) is to provide and maintain reliable, secure and rapid telecommunications to satisfy the requirements of the Joint Chiefs of Staff (JCS) and the needs of naval commanders for the exercise of command and control. Because of greater reliance on communications systems for command and control, the NTS has had to handle increasing volumes of message traffic. In 1981, the Naval Communications Processing And Routing System (NAVCOMPARS) received 12% more messages than in 1980, and transmitted 27% more messages [Ref. 1]. These increasing volumes of naval message traffic are expected to continue. Figure 1.1 depicts the total number of messages received daily by all NAVCOMPARS sites since 1975, and using linear regression, projects the NAVCOMPARS daily received totals through 1986.

The NAVCOMPARS was designed to satisfy the need for a more capable message processing and delivery system. It reduced manual processing and routing of messages as well as the number of personnel required for communications functions by automating other aspects of fleet communications, such as on-line ship-shore and ship-shore-ship circuits.

The NAVCOMPARS is a software system that provides a communications interface between Defense Communications Agency (DCA) networks, local users and the operational fleet. The primary means of communicating with fleet units is through the multichannel fleet broadcast. All underway ships are required to copy an assigned primary broadcast channel, based upon their primary mission area, and a common

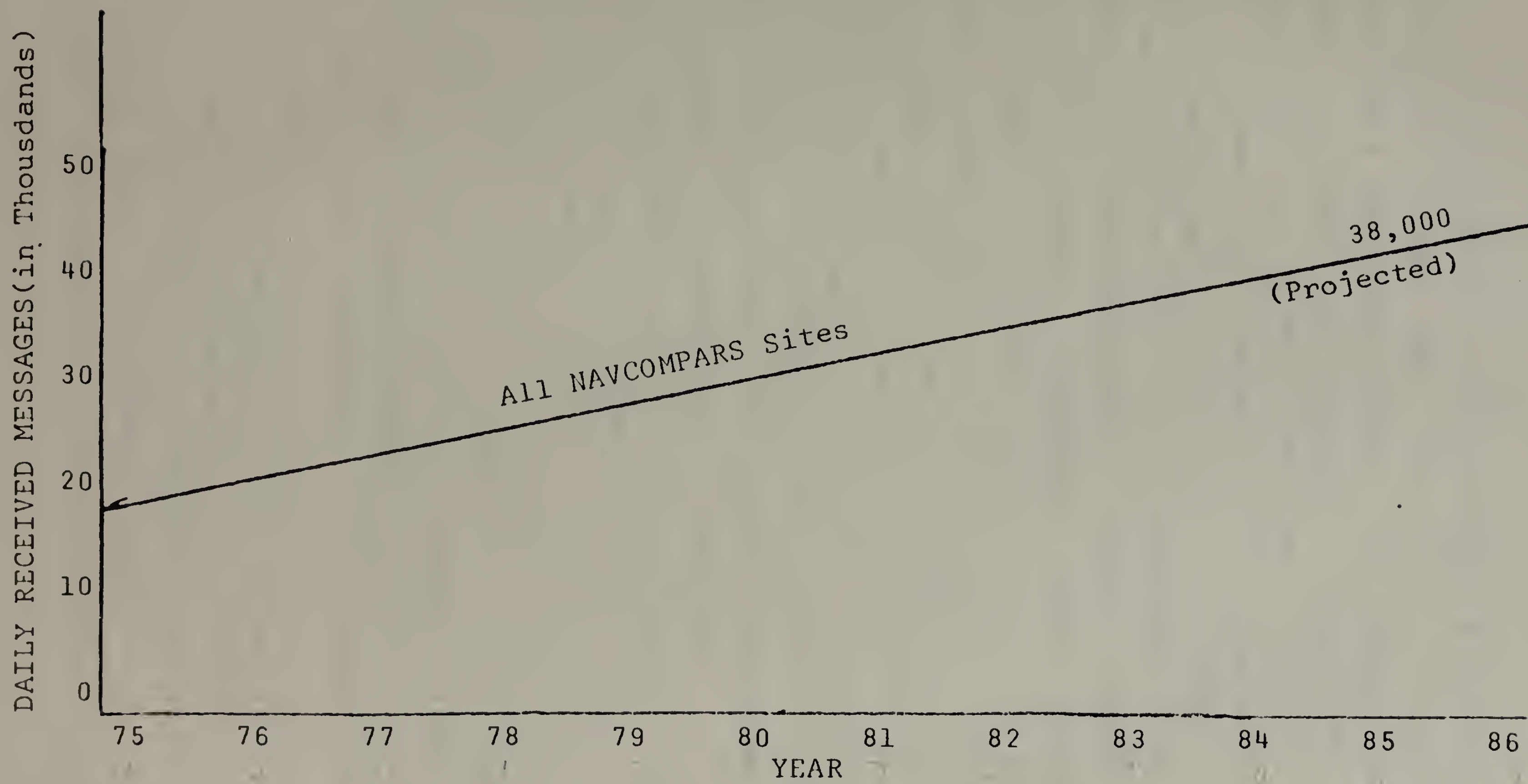

Figure 1.1 NAVCOMPARS Received Message Trend

channel. The multichannel broadcast consists of 16 subchannels, each at an input rate of 75 bits per second (bps). These 16 subchannels are time division multiplexed (TDM) and transmitted at 1200 bps. One of the 16 subchannels is utilized as a frame-sync channel, for proper synchronization of shore and ship TDM equipment. The primary method for transmitting the composite broadcast signal is via satellite. However, high frequency (HF) transmission is utilized in contingency operations and fleet exercises.

The NAVCOMPARS keys the multichannel broadcast on-line, effected by the maintenance of complete guard list files. The system assigns a broadcast channel sequence number (BCSN), starting with 0001 on the first day of each month, for use in responding to fleet broadcast screen requests (BSR). These BSCN's provide an accounting system for the broadcast, which is a "receive only" communications circuit without acknowledgement. Normally, a delayed, automatic rerun channel is assigned for each first run channel of the multichannel broadcast. The system also generates an hourly recap summary for each first run channel.

The NAVCOMPARS receives its message inputs from a variety of sources at differing input rates. However the majority of message traffic is received from two Automatic Digital Network (AUTODIN) circuits, operating at 1200 baud (the number of times per second that the transmitted signal changes its value). Since the message traffic for delivery to the fleet is being transmitted over a 75 bps broadcast, this creates an environment for message queuing at the output circuit.

Queues exist when the message transmission rate (defined as the channel's transmission rate divided by the message length) is exceeded by the message input rate. Due to the stochastic flow of message traffic in communications networks, backlogs will sometimes exist even though the

channel's capacity exceeds the average message flow. However, the required channel transmission speed for any communications channel must exceed the average flow [Ref. 2], and can be expressed by:

$$C \geq \lambda l \qquad \text{(Eqn. 1.1)}$$

where C is the channel's transmission rate (bits/sec)

λ is the average message input rate (messages/sec)

l is the average message length (bits/message)

The above equation expresses the obvious condition that there be enough capacity to satisfy the minimum requirements of the average flow through the communications system. It also gives three simplistic solutions for reducing any existing backlog:

1. Increase the channel's transmission rate.
2. Reduce the message input rate
3. Reduce the message length.

NTS's managers consider a broadcast channel backlog serious when the number of messages awaiting transmission exceeds 100. When a backlog condition exists, communications personnel have the capability of visually inspecting the queues of any specific channel, including each message precedence and intended addressees. Three types of queue status reports are generated by NAVCOMPARS. One report lists the number of queue entries for each precedence level, and a second report adds the intended addressees for each message. The third report consists of queue limit warnings when the channel's queue reaches a predetermined threshold.

The options available to managers for the reduction of broadcast queue buildup are limited to:

1. Activate a broadcast overload channel (also at 75 bps), usually employed when the backlog reaches 150 messages.

2. Altroute equiped subscribers to the Common User Digital Information Exchange Subsystem (CUDIXS), a high speed output channel.

3. Altroute high use subscribers to another broadcast or full period channel (again at 75 bps).

4. Notify high speed input channels to transmit only Category I and II (Flash and Immediate precedence) traffic to the NAVCOMPARS.

Before a communications manager takes any action to relieve a transmission queue buildup, he must first understand the factors that caused it and its resultant effect upon subscribers. This thesis is designed to aid the communications manager in that effort.

II. NAVCOMPARS DESCRIPTION

A. EQUIPMENT FUNCTIONS

The NAVCOMPARS operates on a duplexed UNIVAC series 90/60 series system, which is a communications oriented, medium scale processor. Under this duplexed configuration, one central processing unit (CPU) and its associated equipment are on line while the second CPU is maintained in a backup mode. Table I gives a list of NAVCOMPARS' associated equipment. The CPU consists of magnetic core memory units, program control and arithmetic units, and input/output (I/O) control.

Each CPU has a modular main memory of about 1.5 million bytes (8 bits) capable of off the shelf expansion. The system is capable of handling six levels of memory separation, which ensures program and memory integrity in a multiprogramming environment. It is capable of addressing fixed length units of data of 1, 2, 4, or 8 bytes and variable lengths of data up to 256 characters. The CPU contains 16 general purpose registers, and performs decimal and fixed-point operations, as well as data handling, decision and control operations. The internal logic for the control of elementary operations by the processor is contained in the read-only control memory. A standard set of system interrupts responds to various internal and external conditions affecting system operations. At the time of interrupt, processing can be terminated, suppressed, or completed, depending on the type of interrupt. The interrupt system permits I/O activities to proceed simultaneously with the CPU activities.

TABLE I

NAVCOMPARS Equipment

Model No.	Description	Quantity
	Main Frame Components	
90/60	Central Processing Units	2
5056	Storage Protect	2
5019-45	Clock	2
F1337-99	Selector Channel	2
4015	Console	2
	AUTODIN Interface	
161108	Processor	2
162501	Data Exchange Control	2
165705	AUTODIN Line Control	2
	Direct Access Storage Devices	
8405	Direct access storage control	2
8430	Disk Drives	10
5519	Multichannel Switch	3
90/551	Direct access storage control	1
5513	Multichannel Switch	1
	Input/Output Equipment	
90/227	Paper Tape Reader (punch)	1
5335	Terminate Feature	1
5337	End of Tape	1
0716	Card Reader	2
0604	Card Punch	2
0768	Printer	3
5332-1	ASCII Print Feature	3
5017	Tape Controller	2
0862	Tape Units	10
90/310-24	Standard Interface Unit	1
90/310-25	Standard Interface Unit	1
0768	Console Printer	2
	Communications Equipment	
3024	Front End Processor	2
1928	Communications Controller	2
	Multichannel	
5622	Message Separation	2
90/712	Teletype Buffer	82
90/720-21	Asynchronous data set buffer	14
3542	Video Display Terminal	10
5760	Station Select	10
5763	Operator Attention	10
5765	Screen Address	10
5772	Display Expansion	10
	Optical Character Reader	1
	Paper Tape Reader	2
	TTY Receive only printer	3
5774-200	Local operation cable extension 200 feet	2
	50 feet	6

A multiplexer is an integral part of the CPU, and is capable of accomodating 256 devices, such as direct or sequential access devices in a variety of configurations. Figure 2.1 is a schematic showing the configuration of the equipment. The heart of the communications module is the front end processor (FEP), which provides the computer system's interface with the data transmission devices.

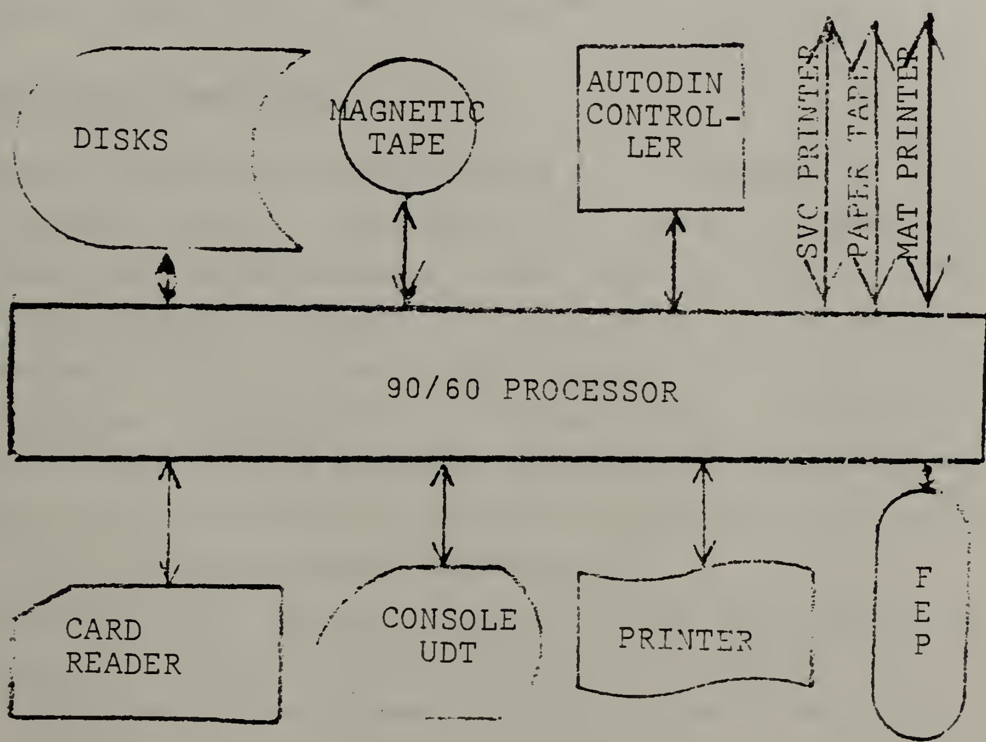

Figure 2.1 NAVCOMPARS Equipment Configuration.

The hardware controls data transmission accuracy through parity checking, with automatic error recovery. An immediate read-after-write occurs on any written data, and any character with bad parity is replaced in its main memory position with the system's error byte.

The system is human monitored and controlled, and management decisions are within the purview of operator personnel. The computer operator interfaces with the system via a set of control switches and a console typewriter, attached to the system by an exclusive trunk of the multiplexor. Operator functions include loading programs or data into memory, monitoring current processing state, and interrupting CPU operations, when required.

B. SUBSYSTEM FUNCTIONS

The NAVCOMPARS software system was designed as a multi-installation system, capable of fulfilling communications needs that are site unique. This flexibility is provided through the modular design of the system, and permits the performance of site unique requirements while maintaining a common system architecture, standard file structure, and standard I/O media and formats. This modularity also permits economical and efficient software maintenance and enhancement, which ensures system reliability.

Central to the design concept of the NAVCOMPARS is the separation of system's functions into a number of subsystems. Tasks to be performed within a subsystem are grouped into logical sets and assigned to program modules. Control over the activities of the modules within a subsystem is maintained by an activity scheduler. Each subsystem has interface requirements with the other subsystems, and does so through common data areas (CDA). However each subsystem was developed as a separate section of software, and can be operated individually or as a group, depending upon the error condition of the system.

Because of the complexity of the overall system, only major characteristics of the NAVCOMPARS subsystems are presented [Ref. 3].

1. Configuration Management Subsystem

The Configuration Management Subsystem (CMS) is the basic subsystem of the NAVCOMPARS. The CMS provides the interface between the hardware and software systems, including the UNIVAC VS/9 operating system. VS/9 is a software package, developed by UNIVAC, that provides all system and I/O control logic for the 90/60 system. CMS controls all system management functions, including subsystem loading, CDA allocation and device acquisition. The CMS interfaces with the various subsystems through supervisor calls (SVC) issued by the subsystems for the allocation of CPU time. CPU time is allocated on a priority basis, the usual allocation is CMS highest, followed by communications I/O functions, communications processing functions and support functions.

2. Communications Control Subsystem

The Communications Control Subsystem (CCS) is an extension of CMS, SVCs requesting communications I/O and communications I/O interrupts are passed to CCS rather than processed in the CMS. CCS allocates all communication devices , and distributes communications interrupts to the appropiate subsystem. The CCS also provides for the processing of logs generated via teleprinter, including the channel log, service log, and the outgoing log. If CCS terminates, all other subsystems will follow since the flow of messages into the NAVCOMPARS will cease.

3. Receive Control Subsystem

The Receive Control Subsystem (RCS) performs all message input processing, editing, intransit storage and initial accountability. RCS is designed as an interrupt driven subsystem capable of interfacing with all sources of input concurrently. Each message received in RCS is recorded

on a disk file (RCDSK), each message received will be dual recorded for recovery purposes. RCS allocates buffers for the receipt of message input, and converts messages received into a common format, Extended Binary Coded Decimal Interchange Code (EBCDIC), for processing. RCS performs the coordination required to ensure that all traffic received is correctly identified by assigning Processing Sequence Numbers (PSN).

4. Message Processing Subsystem

The Message Processing Subsystem (MPS) performs message analysis and validation, routing indicator assignment, and internal distribution assignment. MPS also determines message delivery requirements and performs suspected duplicate processing, to eliminate duplicate messages. MPS provides the NAVCOMPARS interface with Video Display Terminals (VDT) which permit such functions as message entry and recall, message editing, and channel status and control.

5. Transmission Processing Subsystem

The Transmission Processing Subsystem (TPS) provides for transmission channel scheduling, queuing messages for transmission and alternate routing. TPS maintains the PSN Directory and, once transmission is completed, writes the message to the magnetic tape Journal File.

6. Transmission Control Subsystem

The Transmission Control Subsystem (TCS) transmits messages to a communications channel or terminal device. TCS provides format and code conversion, editing and routing line segregation. TCS also generates a Transmission Indicator (TI) for each message transmitted.

7. Support Program Subsystem

The Support Program Subsystem (SPS) performs report generation and file maintenance. SPS maintains the Routing and Distribution File and produces reports of Routing Files, Distribution Files, as well as, message processing statistics and summaries.

C. SYSTEM MESSAGE FLOW

The NAVCOMPARS consists of three basic functions; message input, message processing and message transmission [Ref. 4]. A message will enter the system, undergo a series of processing steps, culminating in the transmission of the message. Figure 2.2 depicts the flow of a message through the NAVCOMPARS's subsystems.

1. Message Input

Messages are entered into NAVCOMPARS from a variety of sources, including AUTODIN, CUDIXS, paper tape reader, card reader, magnetic tape, optical character reader (OCR), teletype (TTY) or the command VDT. Once a message enters the system, the RCS is notified through CCS that a data block has been received. Control of the received message is assumed by RCS for input processing.

RCS is responsible for creating initial on line message storage and has a capacity for 500 queued messages. RCS provides queue limit warnings when the queue size reaches 67% and 80%. When the queue size reaches 485 entries, all input lines are disconnected. At this point, no new messages can be entered into the NAVCOMPARS, unless entered by operator personnel through use of the command VDT. Processing and routing of messages already in the RCS and the succeeding subsystems is unaffected. This condition continues until the queue size is less than 475.

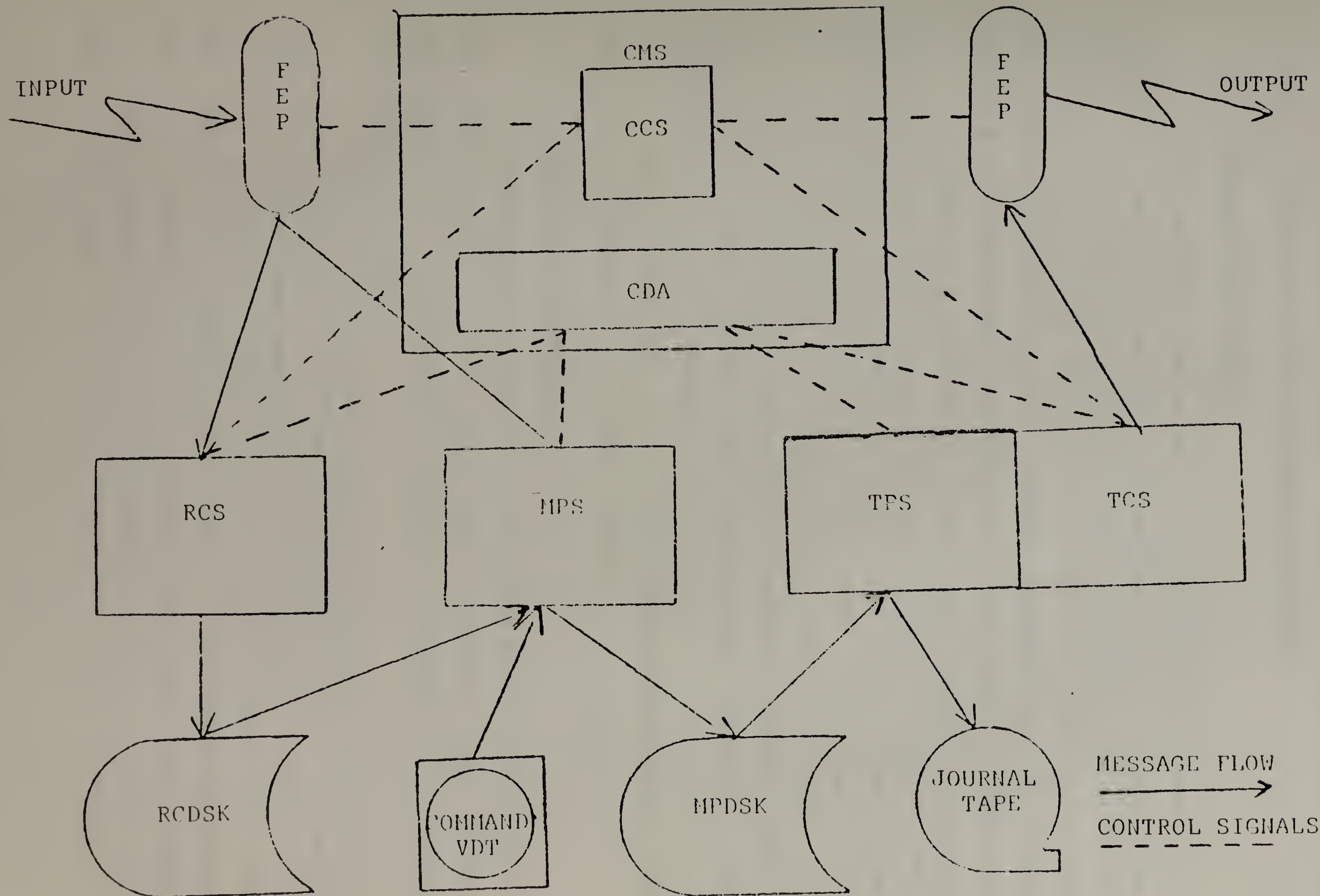

Figure 2.2 NAVCOMPARS Message Flow

After assigning a PSN, and upon completion of input processing, RCS writes the message on RCDSK.

2. Message Processing

MPS controls the message processing environment, it reads the message from RCDSK and validates it, checks format lines. If the message contains some processing restrictions or format errors, the message is routed to a service printer for correction and re-entry. During processing, the message is paged and sectioned (six pages or less equals a section).

MPS has an available queue size of 200 messages. When the queue size reaches 180, only flash or higher precedence messages are accepted. Once the queue size reaches 190, MPS will only receive input from the command VDT. Unlike RCS, MPS does not shutdown as a result of queue size. Should MPS discontinue processing, messages would still be received by RCS, but would eventually result in RCS exceeding the queue limits.

Upon completion of its processing functions, MPS writes the message on its disk (MPDSK).

3. Message Transmission

TPS assumes control of the message in the transmission environment, it reads the message from MPDISK, determines the transmission channel and queues the message for delivery by ICS.

TPS has two queues. Q1 is the Message Accountability queue and consists of those messages pending processing action. Q1 has a maximum size of 6200 messages, 800 of which are core resident. Once the queue size reaches 6090, TPS will accept only immediate, or higher, precedence messages. The second queue, Q2, is the Transmission Queue and consists of those messages awaiting transmission. While a message may appear only once in Q1, it may appear several times in Q2,

depending upon how many delivery circuits are required. Q2 has a maximum queue size of 47000 messages, 4000 of which are core resident.

The message transmission subsystems do not shutdown as a result of queue sizes, however, any failure in these subsystems would result in the inability of the NAVCOMPARS to transmit messages and cause resulting backlogs in the preceeding subsystems.

TPS queues messages for transmission on a first-in first-out (FIFO) basis, by precedence level. Flash, or higher, precedence levels will interrupt any lower precedence level currently being processed, while other precedence levels simply proceed to the head of the line of any lower precedence messages.

Maintenance of the various queues of NAVCOMPARS is a system overhead. Requiring the system to scan large queues for the next job to perform, ties up computer resources that could be used for processing and transmitting messages.

After transmission is completed, the message is written to the journal tape, by TPS, for record purposes.

III. BASELINE STATISTICS

A. MESSAGE INPUT RATE

In order to determine a characteristic message input rate, statistics were examined at the Naval Communications Station (NAVCOMMSTA) Stockton, California. A search was made for a time period where the message volume was representative of normal load and was not affected by any unusual fleet or ashore activity. The day chosen was 30 October 1982, Radio Day (RADAY) 300.

The SPS Processing Traffic Analysis Report (SRPA), was examined for RADAY 300. The number of messages received by RCS per hour and destined for delivery on the common channel (HMCC) of the multichannel broadcast were recorded by precedence level. Table II contains the message input data for RADAY 300. The mean, $\bar{X}$, and standard deviation, σ_X , for each precedence level was chosen as a means of describing the input rates, and was computed using the following equations [Ref. 5].

$$\bar{X} = \sum_{i=1}^{N} X_i / N \qquad \text{(Eqn. 3.1)}$$

$$\sigma_X = \sqrt{\sum_{i=1}^{N} (X_i - \bar{X})^2 / N} \qquad \text{(Eqn. 3.2)}$$

where N is the number of observations made

Table III contains the results of this computation.

TABLE II

Message Input Data Distribution

HOUR	FLASH	IMMEDIATE	PRIORITY	ROUTINE
0000	0	11	7	13
0100	0	3	8	11
0200	0	4	6	5
0300	0	5	6	10
0400	0	2	10	2
0500	0	4	7	4
0600	0	2	3	3
0700	0	2	2	7
0800	0	6	9	10
0900	0	5	7	19
1000	0	2	4	6
1100	0	3	6	9
1200	0	1	8	8
1300	0	2	4	22
1400	0	5	5	12
1500	2	7	9	5
1600	0	3	5	9
1700	2	2	4	7
1800	0	3	1	9
1900	0	1	14	8
2000	6	2	11	6
2100	0	2	8	6
2200	7	4	5	8
2300	1	1	3	7
TOTALS	18	82	152	206

TABLE III

Message Input Rate (per Hour)

PRECEDENCE	MEAN INPUT RATE	STANDARD DEVIATION
Flash	.75	1.87
Immediate	3.41	2.28
Priority	6.50	2.99
Routine	8.58	4.57

$19.24 = \lambda$

B. MESSAGE PROCESSING SPEED

Although messages undergo some processing in both RCS and TPS, message processing is taken here to mean the validation undergone in MPS.

1. CLOCKS Program

CLOCKS is a software program developed to monitor the NAVCOMPARS system queues and measure NAVCOMPARS message processing rates. CLOCKS runs in the background during NAVCOMPARS message processing and measures the total number of messages in both RCS's and MPS's queues. CLOCKS also measures the total number of messages received and processed by RCS and MPS during a certain time interval, and makes processing speed projections, based on this data. This processing speed projection is what is normally referred to as the NAVCOMPARS throughput rate.

CLOCKS can be operated in three modes. Mode one will produce system queue summaries every minute of the monitored interval. In mode two, the system will produce queue summaries for specific time periods, within the monitoring interval. In mode three operation, CLOCKS provides a system queue summary over the entire monitored interval. Figure 3.1 contains summary data of CLOCKS mode two operation, with 5 minute time intervals, for RADAY 300. The mean and standard deviation of this data was calculated, utilizing equations 3.1 and 3.2, and found to be:

$$\bar{X} = 43.66 \text{ (messages per 5 minute interval)}$$

$$\sigma_{\bar{X}} = 9.23 \text{ (messages per 5 minute interval)}$$

This implies a NAVCOMPARS processing speed, or throughput rate of approximately 524 messages per hour. This throughput rate includes all messages processed by the NAVCOMPARS, regardless of transmission channel.

thru

mode

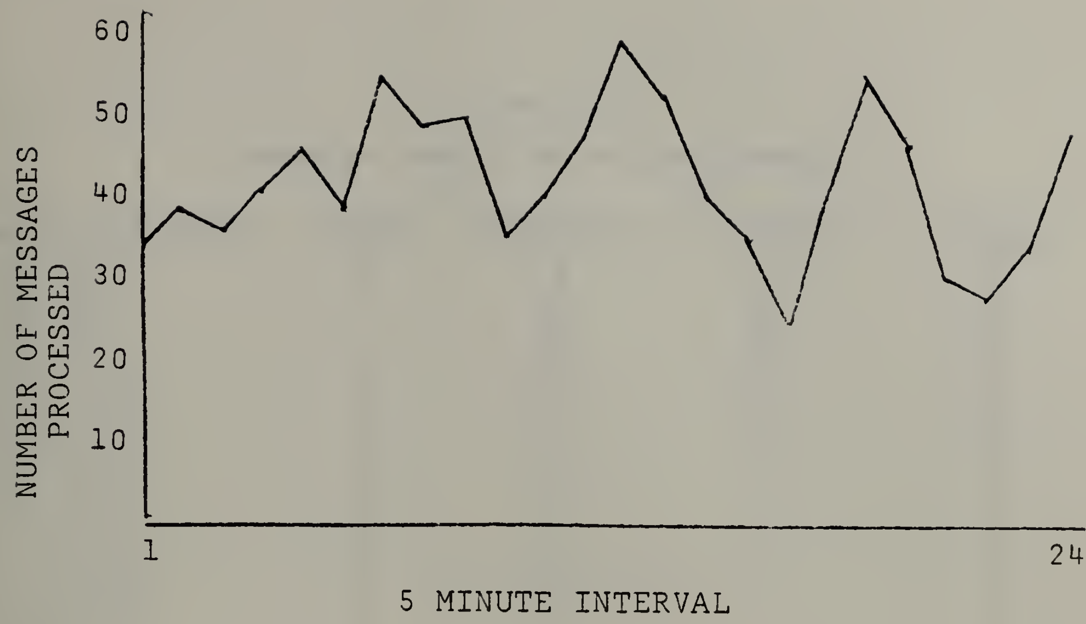

Figure 3.1 Message Processing Speed (CLOCKS).

C. MESSAGE TRANSMISSION RATE

The SRPA does not list the character length of each message transmitted, however, it does list the number of messages whose character length falls within a 200 character interval. This data was examined for HMCC, during RADAY 300, and is presented in Table IV, by precedence levels. The mean for each precedence level was computed, using the midpoint of the interval, and Table V contains these results.

Since the NAVCOMPARS utilizes EBCIDIC for internal operations, the number of characters must be multiplied by 8 to obtain the number of bits per message. The multichannel broadcast utilizes 75 baud transmission lines, thus the transmission time, t ,(in seconds) is equal to the message length (in bits) divided by 75. The inverse of this quanity, when multiplied by 3600, gives the transmission rate, μ ,(per

hour). Table V contains message transmission statistics for RADAY 300.

TABLE IV

Message Length Data Distribution

Character Range	Flash	Immediate	Priority	Routine
0-199	0	0	1	1
200-399	0	0	4	2
400-599	14	19	32	34
600-799	3	13	24	23
800-999	1	13	23	19
1000-1199	0	10	13	14
1200-1399	0	6	14	16
1400-1599	0	9	11	12
1600-1799	0	6	10	9
1800-1999	0	5	9	7
2000-2199	0	4	4	3
2200-2399	0	1	6	2
2400-2599	0	3	0	4
2600-2799	0	0	2	2
2800-2999	0	2	0	4
3000-3199	0	0	1	3
3200-3399	0	1	1	1
3400-3599	0	1	4	3
3600-3799	0	0	4	3
3800-3999	0	0	3	1
4000-4199	0	0	0	1
4200-4399	0	0	1	1
4400-4599	0	0	1	0
4600-4799	0	0	1	1
4800-4999	0	0	2	1
5000-5199	0	0	1	2
5200-5399	0	0	0	0
5400-5599	0	0	0	1
5600-5799	0	0	2	1
5800-5999	0	0	21	16

TABLE V

Message Transmission Statistics

PRECEDENCE	Mean Message Length (characters)	Mean Xmission Time (seconds)	Mean Xmission Rate (per Hour)
Flash	555.5	59.25	60.75
Immediate	1216.1	129.7	27.75
Priority	1928.7	205.7	17.50
Routine	1839.7	196.2	18.35

char x 8 bits / baud

1 / trans time (3600)

D. STATISTICAL ANALYSIS

The average message input rate for HMCC is the sum of the average input rates of all precedence levels and is given by [Ref. 2].

$$\lambda = \sum_{i=1}^{P} \lambda_i \qquad \text{(Eqn. 3.3)}$$

where P is the number of precedence levels

From Table III, this value is approximately 19 messages per hour. When compared to the average message processing speed of MPS (524 messages per hour), it is apparent that the broadcast input rate causes no difficulty for the processing subsystem. This result is expected, and required, since one broadcast channel is only one of many NAVCOMPARS' transmission lines.

The average transmission rates, listed in Table V, are also well below the message processing speed. The result of this speed differential is depicted in figure 3.2 , which lists the hourly message transmission backlog for HMCC, during RADAY 300. The mean hourly backlog was computed to be approximately 35 messages. This backlog is well below the 100 message level, considered acute by the NTS's managers. If an assumption is made that this backlog consists of the lowest precedence level, then its elimination would take over 114 minutes (the backlog miltiplied by the transmission time), if no higher precedence messages are received for transmission. This 114 minutes would be added to the total time each of the lowest precedence messages spends in the system. This illustrates the importance of keeping transmission backlogs at a minimum.

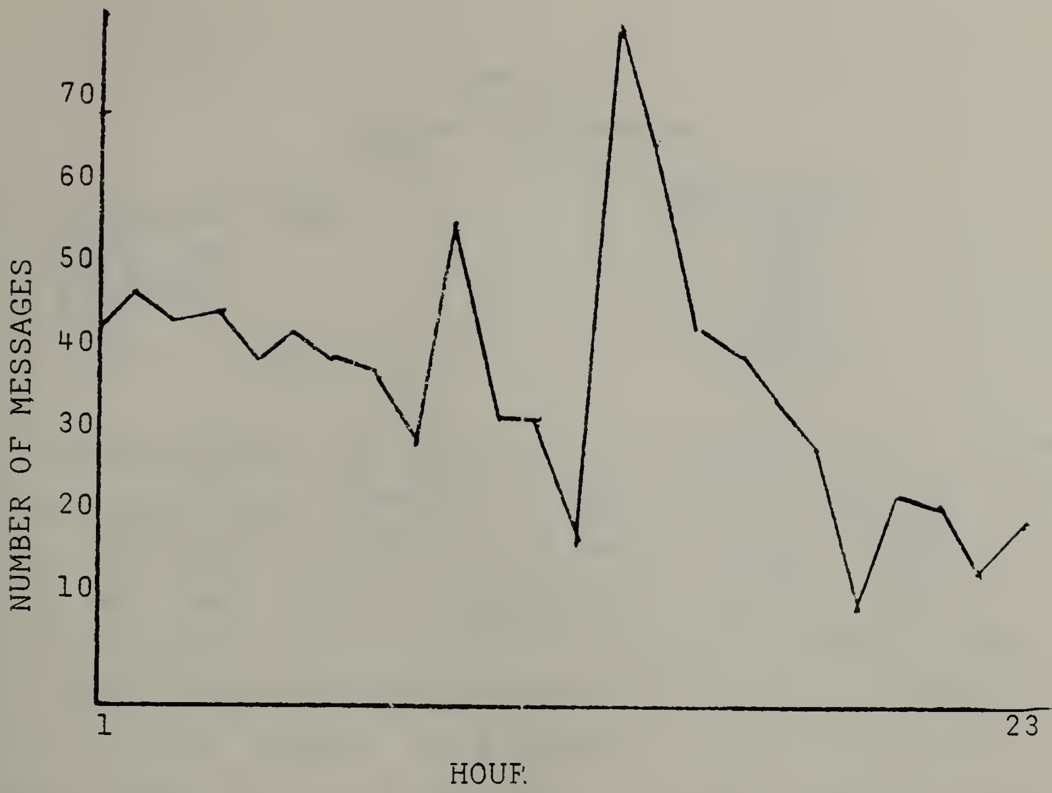

Figure 3.2 Hourly Message Backlog (HMCC).

This speed differential highlights the need for timely action to eliminate broadcast queue build-up during periods of high message input rates.

An indication of the use of a communications channel is given by the ratio of its message input and transmission rates. This measure is called system's utilization, ρ, and is represented by [Ref. 2].

$$\rho = \sum_{i=1}^{P_1} \lambda_i / \mu_i \qquad \text{(Eqn. 3.4)}$$

Where λ is the mean message input rate (messages/hour)

μ is the mean message Xmission rate (messages/hour)

The utilization for each precedence level, of HMCC, was calculated using equation 3.4. Table VI contains these results.

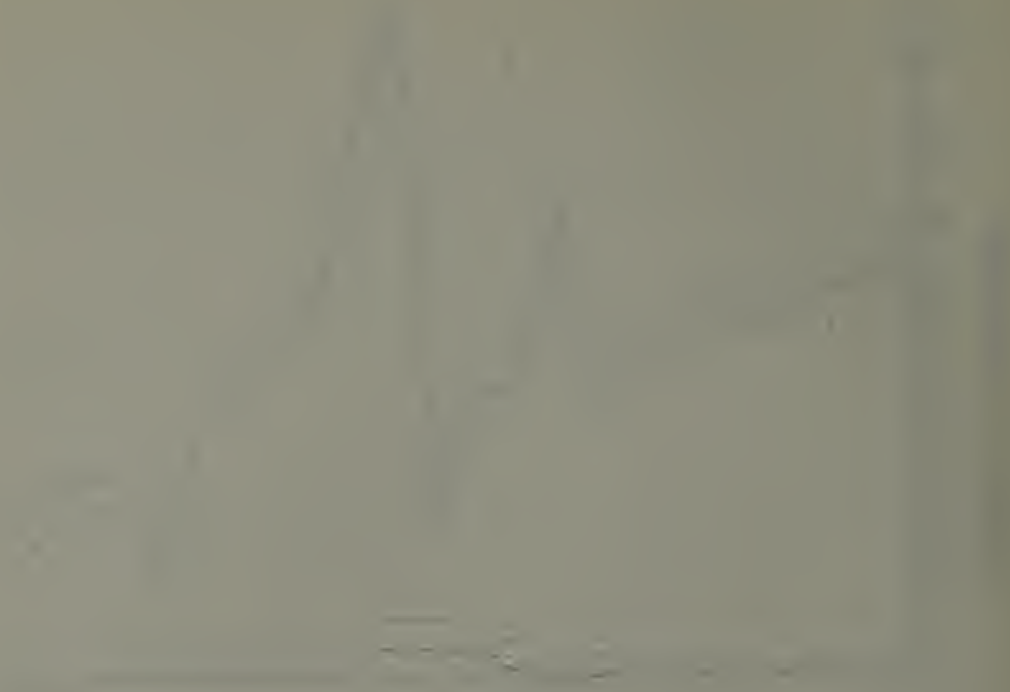

TABLE VI

System Utilization

Precedence Level	Utilization
Flash	.01
Immediate	.12
Priority	.36
Routine	.46
TOTAL	.95

A utilization rate equal to or greater than one would indicate that the transmission queue would increase without bound. The large deviation in message input rates, especially at the Routine precedence level, indicates an explosive situation, since the utilization rate is near one. The closer the system utilization is to one, the greater the delays in the system will become, and the greater the average queue size. A hardware or transmission subsystem failure at such a high utilization rate would result in a rapidly accumulating backlog. Given the speed differential of the NAVCOMPARS's processing and transmission subsystems, this backlog would be almost impossible to eliminate at the broadcast channel's current transmission rate.

An ideal utilization rate is one that provides proper balance between conflicting demands of utilization and delay time. but should probably be around 60 percent. Again, the simplistic solutions would be to either decrease the message input rate or increase the message transmission rate. A ten percent reduction in the average message input rates of Immediate precedence level, and below, would result in an eight percent reduction is system utilization. The message transmission rate could be increased ten percent, by a ten percent reduction in the average message length, and would also result in an eight percent reduction in utilization. The simultaneous employment of both of these measures could achieve significant reductions in the utilization rate, and result in a more responsive communications channel.

IV. MODEL DEVELOPMENT

The employment of an idealized mathematical model, as a descriptive tool, provides ease of analysis. Because of random arrival rates into the system and the system's random service times, a mathematical model may not reflect the system's status at any one instant in time, only an expected value. If interest is in the change of the system over time, then a computer simulation should be employed. Before simulation is attempted, an idealized mathematical model may prove to be a useful tool. However, the idealizations introduced in the model must reflect the essential characteristics of the modeled system.

A. MODEL ASSUMPTIONS

In attempting to fit a mathematical model to the system message flow (as described in Chapter II) the message input rate and the message processing speed differential (presented in Chapter III) supports an assumption that the input rate into the transmission subsystem is the same as that of the receive subsystem. The assumption is also made that there exists no restrictions on message input rates, or that an infinite source exists.

The model is based on an assumption of independence between the message input and transmission rates. The assumption is also made that there exists no problems in transmitting at the channel's transmission rate. Queue sizes are assumed equal to those described in Chapter II and queue discipline is assumed to be FIFO, by precedence level, and no messages are allowed to leave the queue, except by transmission.

1. Poisson Arrival Rate

The message input or arrival rate is assumed to be random, and cannot be predicted with complete accuracy. However, this arrival rate can be described statistically, by means of the Poisson probability distribution function. The probability that the function, f(x), will take on any value, x, is given by [Ref. 5].

$$f(x) = \lambda^{x} e^{-\lambda} / x! \qquad \text{(Eqn. 4.1)}$$

where λ is the mean message input rate (messages/hour)

The observed message input rate was tested against the theoretical probability distribution function, using the Kolmogorov-Smirnov goodness of fit test, and found that the assumption could not be rejected at the .01 significance level. Table VII displays the results of the goodness of fit test.

a. KOLMOGOROV-SMIRNOV Goodness of Fit Test

Goodness of fit refers to the comparison of an observed frequency distribution to theory or assumption. In the KOLMOGOROV-SMIRNOV goodness of fit test, the observed cummulative frequency distribution (CDF) is listed and the theoretical CDF is determined based on the appropiate equation. The deviation is defined as the absolute value of the difference between the cummulative observed and theoretical frequencies. The maximum deviation is compared to the Table of Critical Values, listed in figure 4.1, for determination of the significance level, or the probability of committing a Type I error. A Type I error is committed when a valid assumption is rejected. Usually, an assumption is tested at a .05 or .01 level of significance.

Sample Size (n)	Level of Significance for $D =$ Maximum $\lvert F(x) - S_n(x) \rvert$				
	.20	.15	.10	.05	.01
1	.900	.925	.950	.975	.995
2	.684	.726	.776	.842	.929
3	.565	.597	.642	.708	.828
4	.494	.525	.564	.624	.733
5	.446	.474	.510	.565	.669
6	.410	.436	.470	.521	.618
7	.381	.405	.438	.486	.577
8	.358	.381	.411	.457	.543
9	.339	.360	.388	.432	.514
10	.322	.342	.368	.410	.490
11	.307	.326	.352	.391	.468
12	.295	.313	.338	.375	.450
13	.284	.302	.325	.361	.433
14	.274	.292	.314	.349	.418
15	.266	.283	.304	.338	.404
16	.258	.274	.295	.328	.392
17	.250	.266	.286	.318	.381
18	.244	.259	.278	.309	.371
19	.237	.252	.272	.301	.363
20	.231	.246	.264	.294	.356
25	.21	.22	.24	.27	.32
30	.19	.20	.22	.24	.29
35	.18	.19	.21	.23	.27
Over 35	$\frac{1.07}{\sqrt{n}}$	$\frac{1.14}{\sqrt{n}}$	$\frac{1.22}{\sqrt{n}}$	$\frac{1.36}{\sqrt{n}}$	$\frac{1.63}{\sqrt{n}}$

Figure 4.1 KOLMOGOROV-SMIRNOV Table of Critical Values.

2. Exponential Message Length

The length of messages arriving for transmission on the multi-channel broadcast are also assumed to be random, but can be described by the negative exponential distribution function. The probability that the function, f(x), will take on any value between 0 and x is given by [Ref. 5].

$$f(x) = 1 - e^{-1/x} \qquad \text{(Eqn 4.2)}$$

where 1 is the mean message length (bits/message)

TABLE VII

Message Input Rate Goodness of Fit

MESSAGES	FLASH			IMMEDIATE			PRIORITY			ROUTINE		
	Obs	Exp	O-E	Obs	Exp	O-E	Obs	Exp	O-E	Obs	Exp	O-E
0	.791	.496	.295	.000	.033	.033	.000	.001	.001	.000	.000	.000
1	.833	.844	.011	.125	.146	.021	.042	.011	.031	.000	.002	.002
2	.916	.965	.049	.458	.338	.120	.084	.042	.042	.042	.009	.033
3				.624	.556	.068	.167	.110	.057	.084	.030	.054
4				.707	.741	.034	.292	.221	.071	.126	.074	.052
5				.832	.867	.035	.417	.366	.051	.209	.149	.060
6	.958	1.00	.042	.874	.938	.064	.542	.523	.019	.334	.256	.078
7	1.00	1.00	.000	.916	.972	.056	.667	.669	.002	.459	.392	.067
8							.792	.787	.005	.584	.521	.063
9							.875	.872	.003	.709	.650	.059
10							.917	.927	.010	.792	.760	.032
11				1.00	1.00	1.00	.959	.959	.000	.834	.845	.011
12										.876	.905	.029
13										.918	.944	.026
14							1.00	.988	.012			
19										.960	.992	.032
22										1.00	.998	.002

The observed message length statistics were tested against the theoretical probability distribution, again using the Kolmogorov-Smirnov goodness of fit test, and found that the assumption could not be rejected at the .01 significance level. Table VIII displays the results of this goodness of fit test.

B. MEASURE OF PERFORMANCE

A mathematical model generates several measures of performance upon which the modeled system can be evaluated. The measure of performance utilized in this effort is the average time within the system.

1. Average System Waiting Time

When a message enters the system, the length of time it remains in the system is determined by the amount of time it spends waiting to be served and being served. Under the model's assumptions, the service time is a function of the message length and the channel's baud rate. The average service time or transmission time for each precedence level is listed in Table V.

The amount of time waiting for service is a function of the utilization of the system and the queue discipline, the policies that determine how messages are selected for service. The NAVCOMPARS transmission subsystems utilize both a "preemptive" and "head of the line" priority dispatching. Flash precedence messages preempt or interrupt the transmission of lower precedence messages. While Immediate level, and below, messages proceed to the head of the waiting line for lower precedence messages, without interrupting the transmission of the current message. Because Flash precedence messages represent only one percent of the total utilization, the NAVCOMPARS is treated here as a "head of the line" priority dispatch only.

TABLE VIII

Message Length Goodness of Fit

LENGTH	FLASH Obs	FLASH Exp	FLASH O-E	IMMEDIATE Obs	IMMEDIATE Exp	IMMEDIATE O-E	PRIORITY Obs	PRIORITY Exp	PRIORITY O-E	ROUTINE Obs	ROUTINE Exp	ROUTINE O-E
100							.005	.052	.047	.005	.052	.047
300							.051	.150	.099	.015	.150	.125
500	.778	.593	.185	.204	.337	.133	.189	.239	.050	.197	.238	.041
700	.945	.716	.229	.343	.437	.094	.312	.316	.004	.320	.316	.004
900	1.00	.802	.198	.482	.522	.040	.429	.386	.043	.421	.386	.035
1100				.589	.595	.006	.495	.450	.045	.495	.450	.045
1300				.653	.656	.003	.566	.506	.060	.580	.506	.074
1500				.749	.708	.041	.622	.557	.065	.644	.557	.087
1700				.813	.753	.060	.673	.603	.070	.692	.603	.089
1900				.876	.791	.085	.719	.643	.076	.729	.644	.085
2100				.919	.822	.097	.739	.680	.059	.745	.680	.065
2300				.929	.849	.080	.769	.714	.055	.755	.713	.042
2500				.961	.872	.089				.776	.743	.033
2700							.779	.769	.010	.786	.769	.017
2900				.982	.907	.075				.807	.793	.014
3100							.784	.814	.030	.823	.814	.011
3300				.992	.933	.059	.789	.833	.044	.828	.833	.005
3500				1.00	.944	.056	.809	.850	.041	.844	.850	.006
3700							.829	.866	.037	.860	.866	.006
3900							.844	.879	.035	.865	.880	.015
4100										.870	.892	.022
4300							.849	.903	.054	.875	.903	.028
4500							.845	.913	.059			
4700							.859	.922	.063	.880	.922	.042
4900							.869	.930	.061	.885	.930	.045
5100							.847	.937	.063	.895	.937	.042
5300												
5500										.900	.949	.049
5700							.884	.954	.070	.905	.954	.049
5900							1.00	.959	.041	1.00	.959	.041

An analytical model, that conforms to the described asumptions, was presented by Leonard Kleinrock [Ref. 6], for the determination of the average waiting time within a transmission queue, W_p. This model is given by:

$$W_p = \begin{cases} \dfrac{f(\rho_{j-1}/\mu_{j-1}) + \sum_{i=j}^{p} \rho_i/\mu_i}{\left(1-\sum_{i=p-1}^{p}\rho_i\right)\left(1-\sum_{i=p}^{p}\rho_i\right)} & p \geq j \\ \infty & p < j \end{cases} \qquad \text{(Eqn. 4.3)}$$

where j is the smallest integer such that $\sum_{i=j}^{p} \rho_i < 1$

μ is the mean transmission rate (messages/hour)

ρ is the channel utilization

$$\text{and} \quad f = \begin{cases} 0 & \rho < 1 \\ \dfrac{1-\sum_{i=1}^{p}\rho_i}{\rho_{j-1}} & \rho \geq 1 \end{cases} \qquad \text{(Eqn. 4.4)}$$

Equation 4.3 was utilized to compute the average queue waiting time for all precedence levels, for RADAY 300. This result, when added to the average transmission time for each precedence level, gives the total average time a message spends within the system. Table IX contains this result for all precedence levels, during RADAY 300.

The results presented in Table IX, for Flash precedence traffic, are erroneous since a head of the line priority dispatch model was used. Since this precedence level interrupts the transmission of lower precedence levels, its total time in the system is approximately equal

TABLE IX

Average Time In The System (minutes)

PRECEDENCE	QUEUE WAITING TIME	XMISSION TIME	TOTAL TIME
Flash	2.96	.99	3.95
Immediate	3.41	2.16	5.57
Priority	6.62	3.42	10.04
Routine	115.29	3.27	118.56

to its transmission time. The results obtained for the remaining precedence levels should accurately reflect the average queue waiting times, although the total time in the system would be somewhat longer, because of time spent in the receive and processing subsystems.

C. MODEL'S PREDICTIONS

It is important to note that the results obtained from the use of an analytic model represents the steady state, or long-run behavior of the system. Although this model does not reflect the transient behavior of the system, it is sufficient to predict future long-run behavior under varying input rates.

Historically, the total NAVCOMPARS' message traffic has increased at a linear rate since 1975 (see figure 1.1). This increase is expected to reach 38,000 messages per day for all five NAVCOMPARS sites in 1986, from its 1982 level of 30,000 messages per day. This represents an annual increase of approximately six percent per year.

If an assumption is made that the multichannel broadcast's traffic load will also increase at this rate, while the current percentages of messages in each precedence level remains constant. Table X contains predicted hourly input rates, based on this assumption.

If an assumption is also made that the average message lengths of each precedence level also remains constant during these time periods, then the broadcast channel would

TABLE X

Predicted Message Input Rates (per Hour)

YEAR	FLASH	IMMEDIATE	PRIORITY	ROUTINE
1983	.80	3.63	6.66	9.09
1984	.85	3.85	7.06	9.63
1985	.90	4.08	7.49	10.21
1990	1.21	5.46	10.02	13.66
1995	1.62	7.32	13.42	18.30
2000	2.17	9.79	17.95	24.48

experience higher utilization rates. Table XI contains the predicted utilization for all precedence levels for HMCC, through the year 2000.

TABLE XI

Predicted Broadcast Utilization

YEAR	FLASH	IMMEDIATE	PRIORITY	ROUTINE	TOTAL
1983	.01	.13	.38	.49	1.01
1984	.01	.14	.40	.52	1.07
1985	.01	.14	.42	.55	1.12
1990	.02	.19	.57	.74	1.52
1995	.02	.26	.76	.99	2.03
2000	.03	.35	1.02	1.33	2.73

Based upon this predicted utilization, the average waiting time within the transmission queue can be calculated, using equations 4.3 and 4.4. This result when added to the average transmission time, gives the total time spent in the system. Table XII contains these predicted results through the year 2000.

The above results are all subject to the validity of the assumptions regarding message input rates and message length. Again, the results for Flash precedence messages are inaccurate, however, as the input rate of Flash precedence traffic increases, that level would also experience some degree of queue waiting time. The data in Table XII indicates that the average waiting time, within the queue, for

TABLE XII

Predicted Time In The System (minutes)

YEAR	FLASH Queue	FLASH Total	IMMEDIATE Queue	IMMEDIATE Total	PRIORITY Queue	PRIORITY Total	ROUTINE Queue	ROUTINE Total
1983	3.09	4.08	5.49	7.65	11.33	14.75	∞	∞
1984	4.78	5.77	5.63	7.79	12.39	15.81	∞	∞
1985	4.90	5.89	5.77	7.93	13.29	16.71	∞	∞
1990	5.51	6.50	6.97	9.13	31.07	34.49	∞	∞
1995	8.87	9.86	12.32	14.48	∞	∞	∞	∞
2000	10.97	11.96	17.65	19.81	∞	∞	∞	∞

Routine messages becomes indefinite, starting in 1983, while the average waiting time for Priority messages becomes indefinite in 1995. Table XIII depicts the effect of a ten percent reduction in the average message lengths of all precedence levels, under the assumption of increasing input rates. These results demonstrate that a ten percent reduction in the average message length would decrease channel utilization and waiting times, but would result in an indefinite waiting period for Routine messages in 1985. These results also demonstrate that if message length reduction is to be employed to ensure channel utilization, then reductions of 40 or 50 percent are required if the broadcast channel is to meet communications requirements through the 1990's.

TABLE XIII

Predicted Effect of 10% Reduction in Message Length

YEAR	FLASH Queue	FLASH Total	IMMEDIATE Queue	IMMEDIATE Total	PRIORITY Queue	PRIORITY Total	ROUTINE Queue	ROUTINE Total
1983	2.48	3.36	2.82	3.76	5.17	8.25	45.55	48.49
1984	2.72	3.60	3.13	4.07	6.08	9.16	132.35	135.29
1985	2.84	3.72	3.31	4.25	6.83	9.91	∞	∞
1990	3.85	4.73	4.76	5.70	15.55	18.63	∞	∞
1995	5.20	6.08	6.93	7.87	113.33	116.41	∞	∞
2000	7.11	7.99	10.77	11.71	∞	∞	∞	∞

The current practice of employing an overload channel has the effect of doubling the capacity of the channel and its transmission rates. Table XIV shows the effect, upon waiting times, of employing an overload channel through the year 2000, under the assumption of increasing input rates. While this action would ensure that requirements are met until 1995, it also demonstrates that some combination of both transmission rate increases and message input rate reduction is required to satisfy requirements at the turn of the century.

TABLE XIV

Predicted Effect of Employing a Dedicated Overload Channel

	FLASH		IMMEDIATE		PRIORITY		ROUTINE	
YEAR	Queue	Total	Queue	Total	Queue	Total	Queue	Total
1983	.72	1.71	.78	2.94	1.04	4.46	1.98	5.25
1984	.78	1.77	.85	3.01	1.16	4.58	2.33	5.60
1985	.84	1.83	.91	3.07	1.29	4.71	2.78	6.05
1990	1.15	2.14	1.28	3.44	2.10	5.32	7.99	11.26
1995	1.51	2.50	1.77	3.93	3.70	7.12	∞	∞
2000	2.13	3.12	2.64	4.80	8.82	12.24	∞	∞

V. CONCLUSIONS

The current time objectives for delivery of each message precedence level are promulgated in [Ref. 7]. Table XV lists the writer-to-reader time objectives for naval

TABLE XV

Message Delivery Time Objectives

PRECEDENCE	TIME OBJECTIVE
Flash	10 min
Immediate	30 min
Priority	3 hours
Routine	6 hours

messages. The total writer-to-reader delay, for a message destined for the fleet broadcast, is not given by the total time spent in the NAVCOMPARS. However, because of the normally high speed input circuits (i.e. AUTODIN or CUDIXS), the time spent in the NAVCOMPARS represents a large percentage of the total time delay.

The statistics gathered for RADAY 300, and the application of the analytical model, indicate that the time objectives can currently be satisfied by the multichannel broadcast. Future predictions, based upon an assumption of six percent yearly message growth, indicates that these objectives will not be met in the late 1980's. During this time frame, the utilization of the multichannel broadcast will exceed one and Routine messages would remain in the system indefinitely. During the 1990's the average time spent in the system of all precedence levels will have increased more than 300 percent, and the total system utilization would be over two. This would indicate the requirement of, at least, a full-time broadcast overload channel, in order to satisfy current time objectives.

A. RECOMMENDATIONS

Throughout this effort, three simplistic solutions have appeared:

1. Decrease the message input rate.
2. Increase the channel's transmission speed.
3. Reduce the message length

While either, or all, of these options would improve the utilization rate, and thus channel performance, they are not simple to implement.

The communications manager has a clearly defined staff, or support role, and as such, cannot directly affect the message input rate. However, in the staff role, the communications manager can impress upon commanders, and other users, the effect upon the quality of service (i.e. waiting time) of system over utilization. The model indicates that, not only does an increased load affect average waiting time, but so does increased high precedence utilization. The communications manager should relate the requirement to keep high precedence message input rates as low as possible, if the message precedence system is to serve its function of allowing higher priority traffic to be transmitted as rapidly as possible.

The speed differential between the NAVCOMPARS processing and transmission subsystems indicates a requirement for a contingency delivery system, such as mail, should the system suffer extended outages. With such high utilization rates, messages destined for delivery via the multichannel broadcast, would experience extended queue waiting times after a system outage. Concurrently, it is incumbent upon the communications manager to assist in the development and implementation of alternative methods of satisfying communications requirements, if he is to succeed in an effort to reduce the total message input rate.

There are two means of increasing the message transmission rate, either by increasing the channel's transmission rate or reducing message length. Increasing the channel's tranmission speed is a technique currently implemented through the use on an overload channel. The employment of this option is subject to both the availibility of a vacant channel and the capability of the fleet units to copy the additional channel. An increase in the channel's transmission speed, above 75 baud, would require extensive technological and logistical changes, and is not considered a viable near term option.

The reduction of message length represents the most likely means of increasing the channel's throughput. Communications managers should examine the current format of naval messages to determine if reductions could be made in message overhead, such as message headers. Again, it is the responsibility of the communications manager to inform users of the importance of reducing message length. This is most critical with high precedence traffic, since the occurrence of longer transmission times at these levels, increases the waiting times of all lower levels.

The reduction of message length could be encouraged through the alteration of the present NAVCOMPARS queue discipline. Instead of the present FIFO, by precedence level, a system could be implemented that allows messages to proceed to the "head of the line", within their own precedence level, based on the message length. Users could then be informed that the length of their messages also determines the quality of service received.

Historically, communications managers have attempted to enlist the aid of users in improving the quality of service provided, without the use of penalities or incentives. The above recommendation would end this practice, and result in a more efficient system.

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